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Electron lens parameters for RHIC head-on beam-beam compensation

Y. Luo and W. Fischer
Brookhaven National Laboratory, Upton, NY 11973, USA

Electron lenses (e-lenses) were proposed for the head-on beam-beam compensation in the Relativistic Heavy Ion Collider (RHIC) [1, 2, 3]. As the physics studies of the beam-beam compensation mechanism and the engineering design of the electron lenses are making progress [4, 5, 6], we update the parameters of the proton and electron beams and give the latest layout of the e-lens installation.

1 Locations of RHIC e-lenes

For the RHIC polarized proton run, the two proton beams collide at IP6 and IP8. The proton beam in the Blue ring circulates clockwise, while the proton beam in the Yellow ring circulates anti-clockwise. In the current design, the e-lenses for the RHIC head-on beam-beam compensations are near IP10. Fig. 1 shows the layout of the RHIC ring.

Two e-lenses are needed for the RHIC head-on beam-beam compensation, one for the Blue ring and another one for the Yellow ring. The e-lens for the Blue ring is named BEL, and the e-lens for the Yellow ring is named YEL. In the current design, they are assumed to be 2 m long. They are symmetrically placed 1.5 meter away from IP10. Fig. 2 shows the installation places of the RHIC e-lenses in IR10.

The two proton beams are to be separated vertically. A separation of 10 mm can reliably be reched in operation. The radius of the current beam pipe in IR10 is 60 mm. The electron beams are guided into the compensation regions from the DX horizontal separation magnet side and dumped on the IP10 side. The proton beam of the Blue ring interacts with the electron beam in the BEL, and the proton beam of the Yellow ring interacts with the electron beam in the YEL.

2 Proton beam parameters

Tab. 1 lists the proton beam parameters in the RHIC head-on beam-beam compensation simulation study.

The proton energy is 250 GeV, the relativistic factor is $\gamma = 266$. The bunch intensity is chosen as $N_p = 2.0 \times 10^{11}$. The two proton beams collide at IP6 and IP8. In the current design, the beta functions at IP6 and IP10 are $\beta^*_{x,y} = 0.5$ m. The beta functions at IP10 is $\beta^e_{x,y} = 10$ m. The beta functions at the other crossing points (IP2, IP4, IP10) are 10 m. The beta functions at the two ends of the e-lenses are 10.2 m and 11.2 m.

At the beginning of a store, the proton beam rms transverse emittance is assumed to be 2.5 mm·mrad (15 mm·mrad for the 95% emittance) and the the proton beam size at IP10 is 0.31 mm. At the end of store, the rms transverse emitance is assumed to be 4.17 mm·mrad (25 mm·mrad for the 95% emittance) and the proton beam size at IP10 is 0.40 mm. Fig. 3 shows the beta functions and the beam size versus the distance from IP10.

For the simulation study, the working point of the proton beam is chosen as $(28.695, 29.685)$. The linear chromaticities are set to $Q'_{x,y} = +1$. The multipole magnetic field errors in the triplet quadrupoles and separation dipole magnets in the IRs are included.

The normalized rms longitudinal bunch area of the proton beam is assumed to be 0.17 eV·s. With the acceleration rf cavities, the harmonic number is 360 and the total rf voltage is 300 kV. The relative rms momentum spread of the proton beam is $\delta_{rms} = (\frac{\Delta p}{p_0})_{rms} = 0.14 \times 10^{-3}$, the rms bunch length of the proton beam is $\sigma_l = 0.44$m. While with the storage rf cavities, the harmonic number is 2520 and the total rf voltage is 3500 kV. The relative rms momentum spread of the proton beam is 0.43×10^{-3}, and the rms bunch length is $\sigma_l = 0.15$m.

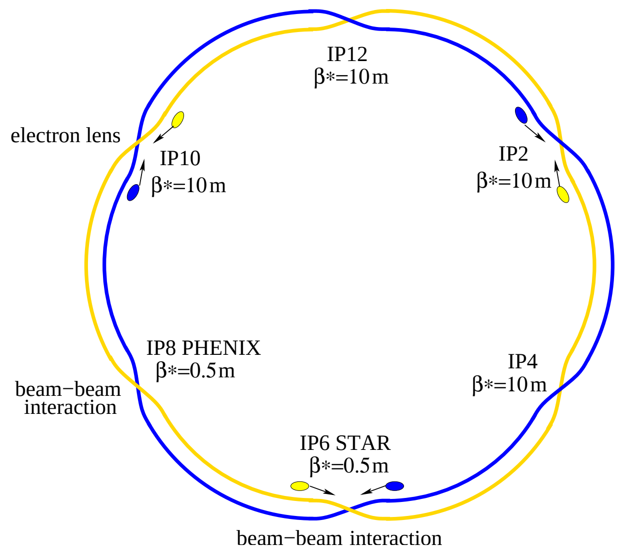

Figure 1: Layout for the simulation.

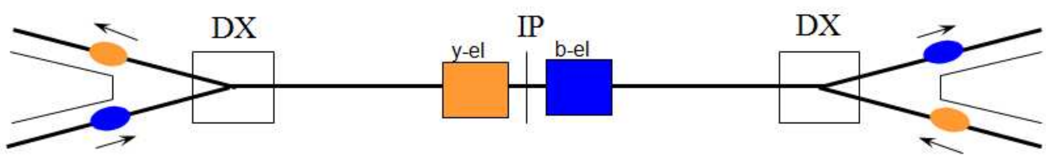

Figure 2: RHIC e-lenses at IP10.

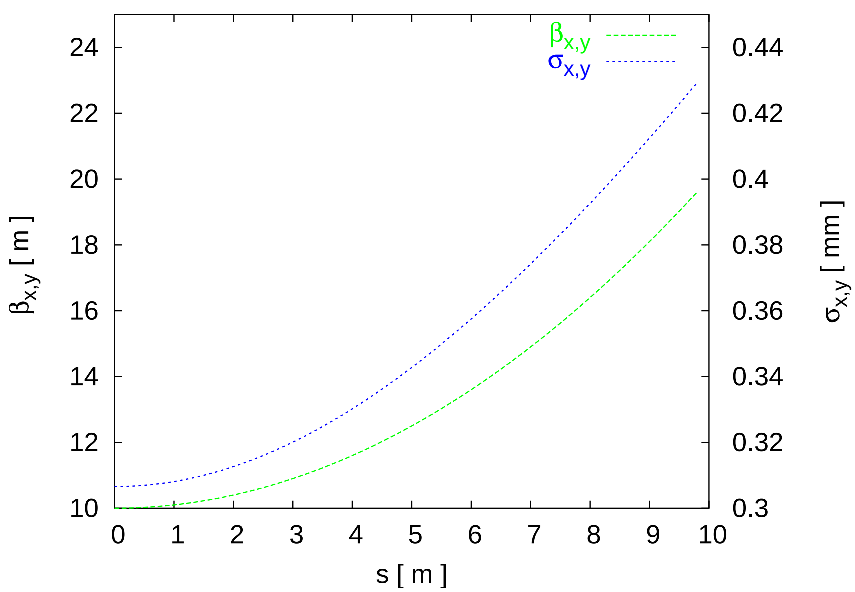

Figure 3: Beta function and proton beam size versus the distance from IP10. In this calculation, the rms transverse emittance of the proton beam is assumed to be 2.5 mm·mrad.

Table 1: Parameters for the proton beams

quantity	unit	value	
lattice			
ring circumference	m	3833.8451	
energy	GeV	250	
relativistic γ	-	266	
beam-beam collision points	-	IP6, IP8	
beam-beam compensation point	-	IP10	
$\beta^*_{x,y}$ at IP6 and IP8	m	0.5	
$\beta^e_{x,y}$ at IP10	m	10	
$\beta^*_{x,y}$ at all other IPs	m	10	
proton beam			
particles per bunch N_p	-	2×10^{11}	
normalized transverse rms emittance $\epsilon_{x,y}$	mm·mrad	2.5	
transverse rms beam size at collision points $\sigma^*_{x,y}$	mm	0.068	
transverse rms beam size at e-lens $\sigma^e_{x,y}$	mm	0.31	
transverse tunes (Q_x, Q_y)	-	$(28.695, 29.685)$	
chromaticities (ξ_x, ξ_y)	-	$(1, 1)$	
beam-beam parameter per IP $\xi_{\mathrm{p}\rightarrow\mathrm{p}}$	-	-0.01	
longitudinal parameters			
		Acceleration rf system	Storage rf system
harmonic number	-	360	2520
rf cavity voltage	kV	300	3500
rms longitudinal bunch area	eV·s	0.17	0.17
rms momentum spread	-	0.14×10^{-3}	0.43×10^{-3}
rms bunch length	m	0.44	0.15

3 E-lens parameters

Tab. 2 summarizes the nominal parameters for the RHIC e-lenses.

In the current RHIC e-lens design, the interaction region of the proton and electron beams are 2 m long. The electron beam is a DC beam and has a round Gaussian transverse profile. The kinetic energy of the electrons is $E_k = 5$ keV.

The best head-on beam-beam compensation requires that the electron beam has the same transverse profile as that of the proton beam. However, in the current study, we assume the electron beam size is constant in the whole luminosity production store. The electron beam size is set to be the proton beam size at the end of store, that is, 0.40 mm rms radius.

For the full head-on beam-beam compensation at matched beam sizes, the number of electrons in the interaction region is 3.5×10^{11}, which gives an electron beam current about 1.2 A. Full head-on beam-beam compensation means compensating the total linear beam-beam tune shift from the proton-proton collisions at IP6 and IP8.

A superconducting solenoid is needed to stabilize the electron motion in the e-lenses. To cancel their betatron coupling effect to the proton beams, the directions of the solenoid magnetic fields in the BEL and YEL should be opposite.

References

[1] Y. Luo and W. Fischer, “Outline of using an electron lens for the RHIC head-on beam-beam compensation”, BNL C-AD AP Note 286, August 2007.

[2] V. Shiltsev, “e-lenses for RHIC and LHC”, 2005 RHIC APEX Workshop, Nov.9-10, 2005, BNL. http://www.c-ad.bnl.gov/APEX/agenda.htm.

[3] V. Shiltsev, X. L. Zhang, G. Kuznetsov, H. Pfeffer, G. Saewert, A. Semenov, D. Wolff, R. Hively, V. Kamerdzhiev, A. Martinez, A. Klebaner, K. Bishofberger, F. Zimmermann, M. Tinov, A. Kuzmin, I.

Table 2: Parameters of RHIC e-lenses.

quantity	symbol	unit	value
electron beam parameters			
electron kinetic energy	K_e	keV	5
electron speed	$\beta_e c$	...	0.14c
electron transverse rms size	σ_e	mm	0.57
effective e-lens length	L_{elens}	m	2.0
full head-on BB compensation			
total electron particles in the e-lens	N_e	-	3.5×10^{11}
electron beam current	I_e	A	1.2

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[4] Y. Luo, etc., "Simulations for RHIC with head-on compensation", LARP Mini-Workshop on Beam-Beam Compensation, SLAC, July 2007.

[5] Y. Luo, etc., "E-lens work for RHIC", the 9th LARP Collaboration Meeting, SLAC, October 2007.

[6] RHIC e-lens meetings can be found at

`http://www.cadops.bnl.gov/AP/BeamBeam/2007_elens_meeting.html`.